Semi-Annual Report
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A. Task Objective: Algorithm Development for Global Mapping of Phycoerythrin Pigment, Dissolved Organic Matter, and Chlorophyllous Pigment

1. MODIS North Atlantic Test Site Establishment and Characterization

previously reported, the MODIS North Atlantic Test Site has been established as originally proposed. The Test Site includes the New York Bight / Mid-Atlantic Bight / Gulf Stream / Sargasso Sea and is conveniently located north and east of GSFC / WFF. Characterization has been initiated by ship sampling, aircraft overflights, and analysis of historical data available from within the NASA AOL project since 1980. Much of the data obtained in the northwestern portion of the test site will be used for algorithm development in Case 2 waters.

A. During this 6-month reporting period the Test Site was both characterized and used as a source of new experimental airborne active-passive ocean color data in pursuit of this team member's algorithm for the detection and mapping of the phytoplankton chlorophyll accessory pigment, phycoerythrin. For the first time, ship samples were taken for the purpose of providing quantitative pigment extractions to calibrate the airborne data for development of the phycoerythrin algorithm. The active (laser) airborne detection of phycoerythrin has been established since 1979 and the evidence for passive (solar) detection at 600nm was published in 1986 and 1990.

Dr. Maria Vernet of Scripps Institution of Oceanography, internationally recognized for her work with phycoerythrin pigment, acquired surface water containing the phycoerythrin pigment. The samples were acquired during a transit of the Research Vessel Cape Henlopen from Bermuda to its home port at the Marine Science Center field laboratory of the University of Delaware in Lewes, Delaware. This use of the vessel was in cooperation with cruise Chief Scientist, Dr. James Ammerman of Texas A&M University. Two overflights with the NASA Airborne Oceanographic Lidar were conducted in March, 1993. The ship measurements of phycoerythrin pigment will be used to establish a transfer function for converting the airborne laser-induced fluorescence measurements into absolute concentration units. While the airborne operations were aggravated by persistent partial cloud cover, the acquired airborne active passive data appear at this time to be of acceptable quality and of sufficient quantity to allow an initial evaluation of the level of phycoerythrin pigment concentration. The work schedule of Dr. Vernet has prevented the immediate extraction of the pigment in her laboratory at Scripps. It is anticipated that the extractions will be completed by the next quarter.

Dr. Vernet also acquired filtered samples to allow further evaluation of the dissolved organic matter (DOM) within the MODIS Test Site from the Delaware Bay mouth across the shelf, slope, Gulf Stream and Sargasso Sea waters. The spectral absorption and fluorescence of these samples are being measured by Dr. Tony Vodacek, National Research Council post-doctoral scientist.

Another flight was conducted to the northeast of GSFC / WFF in early April 1993 to characterize the MODIS Test Site during the collapse of the spring phytoplankton bloom. In addition, this flight allowed the concurrent evaluation of a new multichannel array detector manufactured by Analytical Spectral Devices, Inc. (loaned to AOL the project). Additionally, the evaluation of a sea surface temperature sensor manufactured and loaned to the project by Heimann / EG&G was conducted. The color sensor was found to lack the requisite sensitivity for ocean color spectra in a high-rate / low-integration-time mode needed to allow editing of data containing sun glint. The temperature sensor needs further flight and data evaluation before conclusion to purchase is finalized.

2. Selection of Case 1 Data Sets.

Airborne active-passive ocean color data acquired within Case 1 oceanic regions with the NASA Airborne Oceanographic Lidar is now being screened for use in algorithm development. Several promising candidate data sets have been identified. In particular, AOL active-passive data in the northwestern Atlantic Ocean east of St. Johns , Newfoundland (obtained in 1989 as part of the Joint Global Ocean Flux Study of the North Atlantic Bloom Experiment) has displayed remarkable quality and freedom from non-chlorophyllous backscatterers. This data is being used to establish the baseline radiance model to be used for the retrieval of phycoerythrin pigment (as well as DOM and pigment).

B. Work Accomplished

1. In-situ and Airborne Optical Characterization of MODIS North Atlantic Test Site.

The validity of the Test Site samples and data have been addressed during this reporting period. Specifically, the DOM absorption from prior cooperative ship experiments (see below) have been used to establish the levels of DOM fluorescence measured with the NASA Airborne Oceanographic Lidar in both the Atlantic and Pacific Oceans. These results are in press [F.E. Hoge, R.N. Swift, J.Y. Yungel, and A. Vodacek, Fluorescence of Dissolved Organic Matter: A comparison of North Pacific and North Atlantic Oceans during April 1991, JGR- Oceans 1993].

Some of the data used in the above publication came from the in situ characterization of the test site as initiated on February 28, 1991 with the acquisition of surface layer samples obtained during the Surface Wave Dynamics Experiment (SWADE). As previously reported, through cooperation with Dr. Charles Flagg, arrangements were made to collect 20 samples along an in-bound track line from the Gulf Stream to the mouth of the Delaware Bay. The samples were filtered (0.45 um) to remove particulate matter other than the dissolved organic matter (DOM). Spectral absorbance of the filtered samples were acquired at Wallops, Cornell Laboratory for Environmental Remote Sensing (CLEARS), and Woods Hole Oceanographic Institute (WHOI). Spectral fluorescence of the filtered samples was also measured at CLEARS (Dr. Tony Vodacek, now a NRC Resident Research Associate at Wallops) and WHOI (Dr. Niel Blough).

Recovery of the absorption coefficients for the light-absorbing or chromophoric components of the dissolved organic matter (aCDOM) from their fluorescence emission has been investigated by laboratory analyses of the surface samples gathered from the Feb. 28, 1991 cruise as well as other cruises. These absorbance and fluorescence analyses, (and work reported by others), suggest that absorption coefficients in the near ultraviolet can be directly retrieved from measurements of the fluorescence emission of CDOM. Thus, absorption coefficients in the visible spectrum can potentially be obtained from the fact that CDOM absorption is exponentially related to wavelength. The errors in the laboratory fluorescence measurements were minimized through the combined use of the water Raman scatter as an internal radiometric standard and a quinine sulfate solution as a reference. This methodology reduces aCDOM algorithm retrieval errors primarily attributable to the use of commercial spectro-photometers having maximum optical path lengths of 10 cm. The use of merging technologies, such as the long-path reflecting tube absorption meter and the integrating cavity absorption meter, are suggested for future improvements to aCDOM retrieval algorithms. While the aCDOM retrieval appears feasible, the relationship to CDOM emission is susceptible to changes in fluorescence yield, so the continued temporal study of marine samples from many diverse oceanic locations is needed. When applied to shipboard and aircraft laser fluorometers, this retrieval methodology and the resulting DOM absorption coefficients will be used in ocean color models and associated satellite sensor / algorithm development directly aimed at phycoerythrin retrieval. The DOM is important since it is a major interferant to the detection and quantification of chlorophyll and chlorophyll accessory pigments (CAP) such as phycoerythrin. Likewise, it is a contributor to the carbon cycle itself.

2. In Situ Optical Characterization of the MODIS North Atlantic Test Site.

The continued characterization of the Test Site is partially described in a recent in-press publication titled: "Inherent Optical Properties of the Ocean: Retrieval of the Absorption Coefficient of Chromophoric Dissolved Organic Matter from Fluorescence Measurements" by F.E. Hoge, A. Vodacek, and N. Blough, L&O 1993. Much of the data within this paper was obtained as follows:

a. Through the cooperation of Dr. George Luther of the University of Delaware, 9 filtered and 9 unfiltered samples were gathered during a cruise of the Research Vessel Cape Henlopen on March 4, 1992. (An overflight of the vessel was conducted on March 4, 1992. The purposes of this flight were to (1) calibrate the DOM fluorescence to water-Raman ratio [F(450)/R(401)] and to (2) provide a cross-shelf reconnaissance survey of the team member's MODIS North Atlantic Test Site during a periods not covered by historic AOL missions). The preliminary results indicated a surprising amount of phycoerythrin-bearing organisms already present in early March. Past flight historical experience has shown that the phycoerythrin-containing phytoplankton tend to peak during late March to early April. The ship samples will be used to complement the previous samples and data base to improve the accuracy of the resulting algorithm(s).

b. Participation with the Airborne Oceanographic Lidar in Dr. Kendall Carder's TAMBEX II cruise of the Suncoaster in the Gulf of Mexico during the week of May 11, 1992. (Note that Dr. Carder is both a MODIS and a HIRIS Science Team Member). One of the prime objectives of this cruise was to obtain the necessary in situ ocean color data to address the CDOM algorithm development of Dr. Carder. Excellent airborne active-passive data were obtained for use in our own algorithm development as well. The absorption/fluorescence linearity published in the above paper was also established using this data. No significant phycoerythrin pigment fluorescence was observed with the AOL in the Gulf of Mexico, so no pigment extractions were attempted using the shipboard filtered samples.

D. Anticipated Activities During Next Half Year.

1. Phycoerythrin Algorithm Development Activities

Plans call for us to again directly address the quantification of the phycoerythrin signal as outlined in our own MODIS proposal. To assist us in this endeavor, we will utilize the data obtained by Dr. Maria Vernet (during a cruise previously mentioned herein). Dr. Vernet is an established phytoplankton scientist from the Scripps Institution of Oceanography. Additional (1) CDOM data and (2) first-time ship calibration of the airborne phycoerythrin-to-water Raman signal is potentially obtainable from this field work.

2. Chlorophyll Pigment and CDOM Corrections to the Phycoerythrin Algorithm.

Major perturbations or influence to the ocean color spectrum are provided by chlorophyll and CDOM. These oceanic constituents significantly impede the retrieval of phycoerythrin pigment from the upwelled radiances. Accordingly, they must be dealt with in a systematic way in order to understand their effects and the impact on the retrieval of phycoerythrin and its ultimate quantification. In situ and airborne data gathered to date will be used to model the effects to ascertain the extent that they can be quantified and removed.

3. Additional flights of the NASA Airborne Oceanographic Lidar are planned.

A. For the MODIS Test Site during August, 1993 and October, 1993 cooperative overflights of EOS Interdisciplinary Team member, Dr. N. Blough, will be conducted. He will be aboard the Research Vessel Cape Henlopen conducting DOM investigations in the Mid-Atlantic Bight (and within our own Test Site). Not only will these flights serve as a valuable data source for algorithm development, but they will also serve as a precursor to additional important missions to be described next.

B. During late October and early November 1993 flights will be conducted in cooperation with NSF's Joint Global Ocean Flux Study of Iron Enrichment in the Eastern Equatorial Pacific. Considerable Case 1 ocean color data will be obtained during these JGOFS flights both during the mapping of the ship-deployed iron and during the transit to and from the experiment site at -90W and -5S. Quality algorithm-development ocean color data will also be obtained on predetermined transects within the expected naturally-occuring Galapagos Island plume. The transit flights from Wallops Flight Facility to Guayaquil (via San Jose, Costa Rica) are likewise expected to yield a wealth of ocean color data suitable for algorithm development. During the latter transit flights, numerous different watermasses will be crossed depending on the choice of one of several flight scenarios already studied.

4. The lack of a 600nm band on MODIS-N is the biggest problem facing the retrieval of the phycoerythrin pigment on the first sensor launch. Plans to synthesize a 600nm band from existing bands will be performance tested using data obtained over actual oceanic phycoerythrin pigment using the 32-band AOL passive ocean color subsystem (POCS). Recent studies of available models, however, suggests that the retrieval of the phycoerythrin pigment at the absorption peaks of 495nm (phycourobilin, PUB) and 545nm (phycoerythrobilin, PEB) may possibly be achieved using the 490nm and 555nm MODIS bands. Such retrievals will require a highly accurate model to account for the significant amounts of chlorophyll and DOM absorption occurring simultaneously with the phycoerythrin absorption.